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(12) **United States Patent**  
**Brandes**

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(54) **LIGHT EMISSION DEVICE AND METHOD UTILIZING MULTIPLE EMITTERS AND MULTIPLE PHOSPHORS**

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(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 233 days.

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“White Light LED, Part Nos. NSPW300BS and NSPW312BS, High Brightness LEDs”, Nov. 12, 1999, Publisher: Nichia Corporation.

(51) **Int. Cl.**

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*H01L 33/00* (2006.01)

*H01J 1/62* (2006.01)

(52) **U.S. Cl.** ..... **313/501**; 313/502; 257/89; 257/98

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(74) *Attorney, Agent, or Firm*—Vincent K. Gustafson; Intellectual Property/Technology Law; Julio Garceran

(58) **Field of Classification Search** ..... 313/501–503; 257/88, 89, 98–100

(57) **ABSTRACT**

See application file for complete search history.

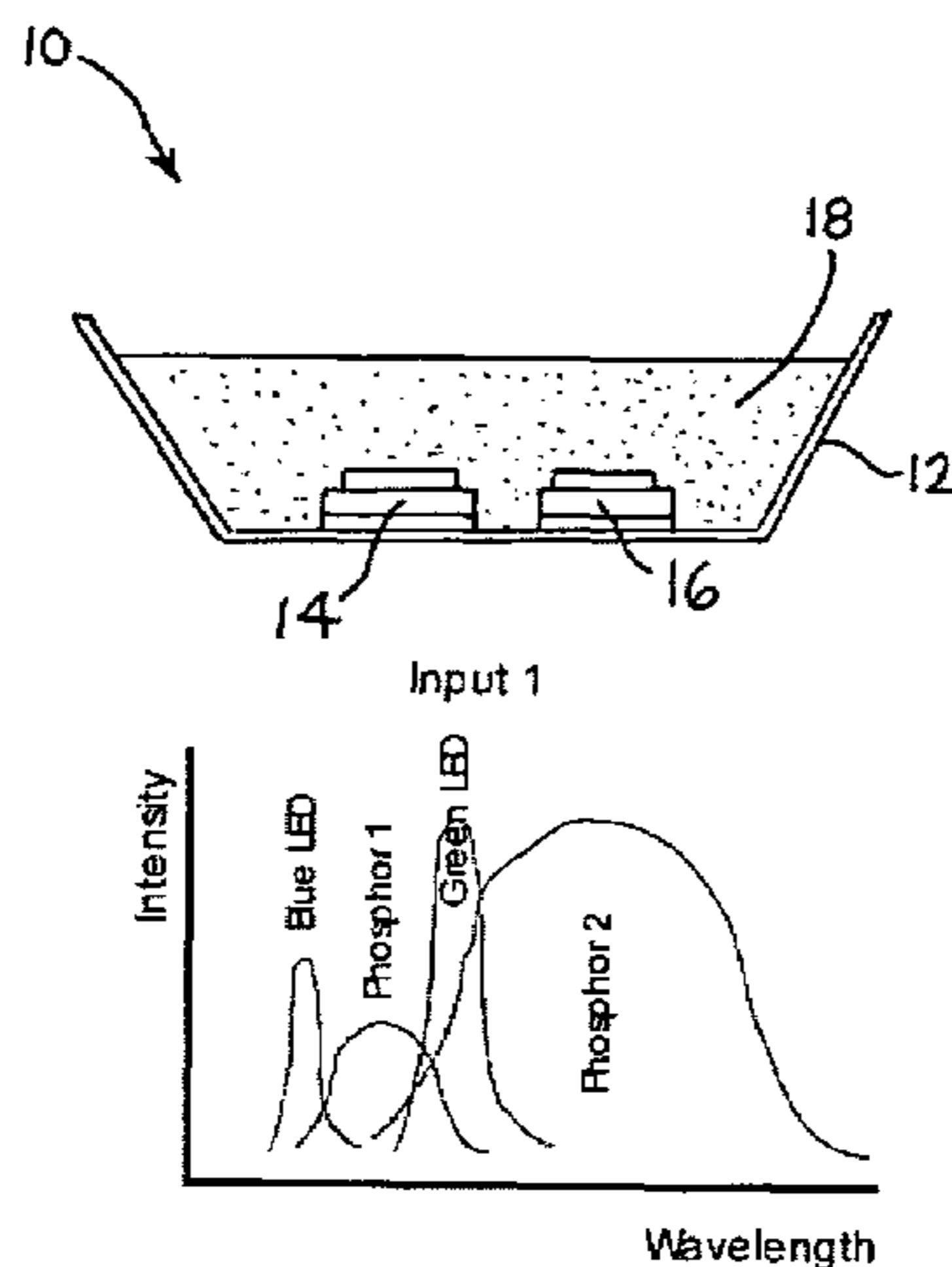
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A light emission device, including at least two LED dies having differing spectral output from one another; and phosphor material including one or more phosphors, arranged to receive spectral output from at least one of the LED dies and to responsively emit a phosphor output, as a component of a spectral output of the light emission device. In a specific arrangement, the multiple LED dies and phosphor material are arranged to produce a white light output having a color temperature selected from among (i) color temperature in a range of from 1350° K to 1550° K, (ii) color temperature in a range of from 2400° K to 3550° K and (iii) color temperature in a range of from 4950° K to 6050° K.

**32 Claims, 7 Drawing Sheets**



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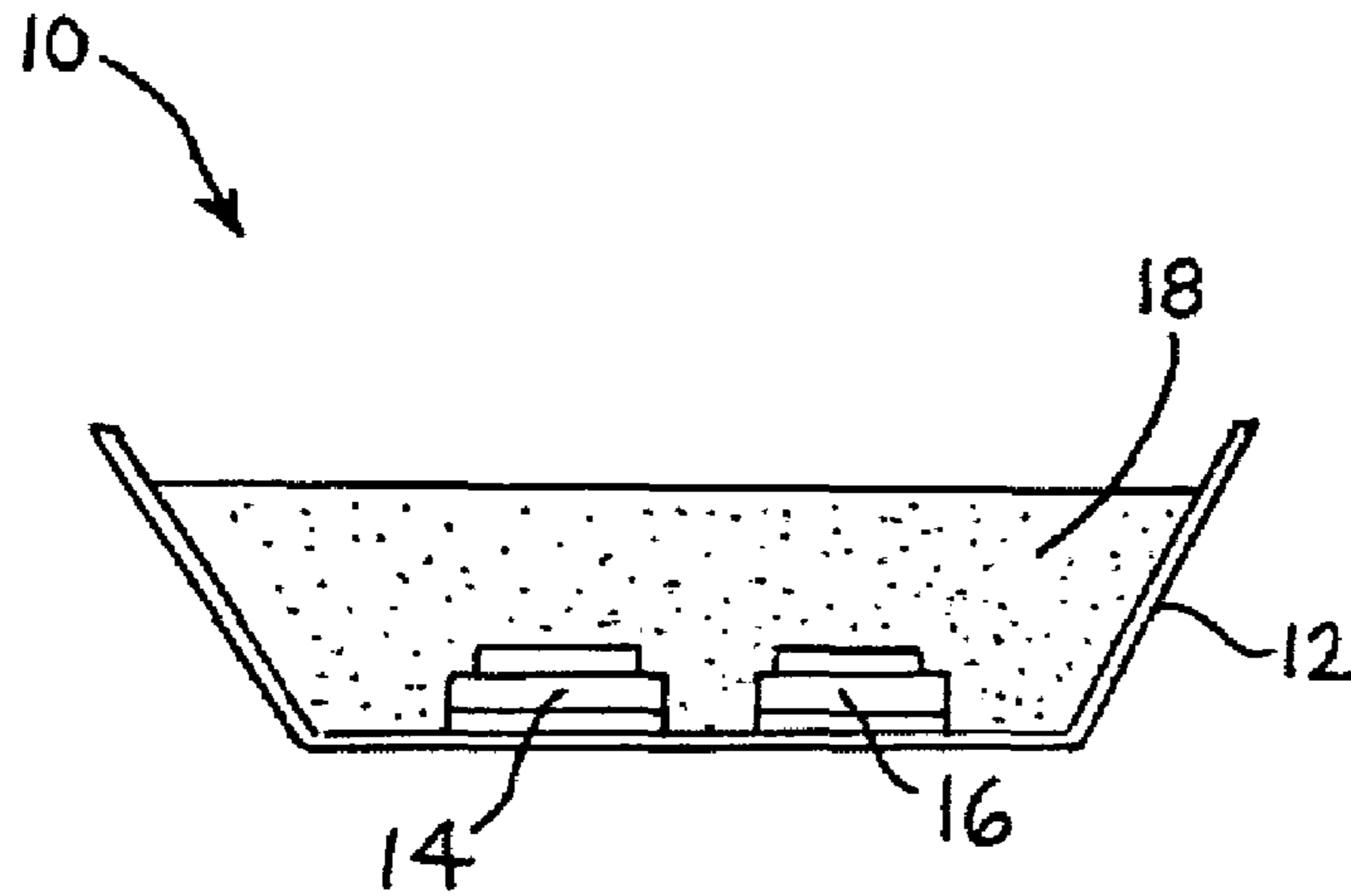


FIG. 1

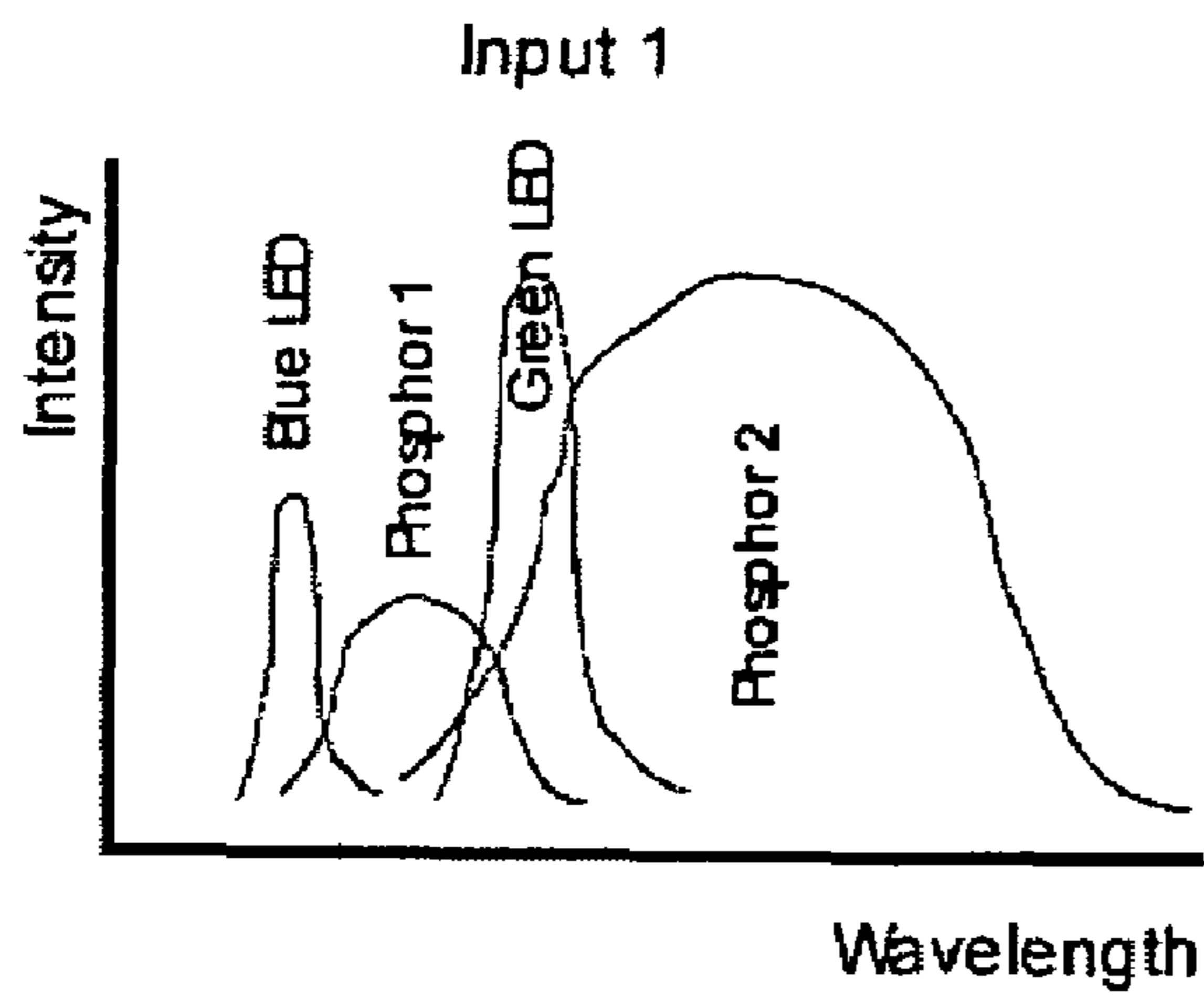


FIG. 2

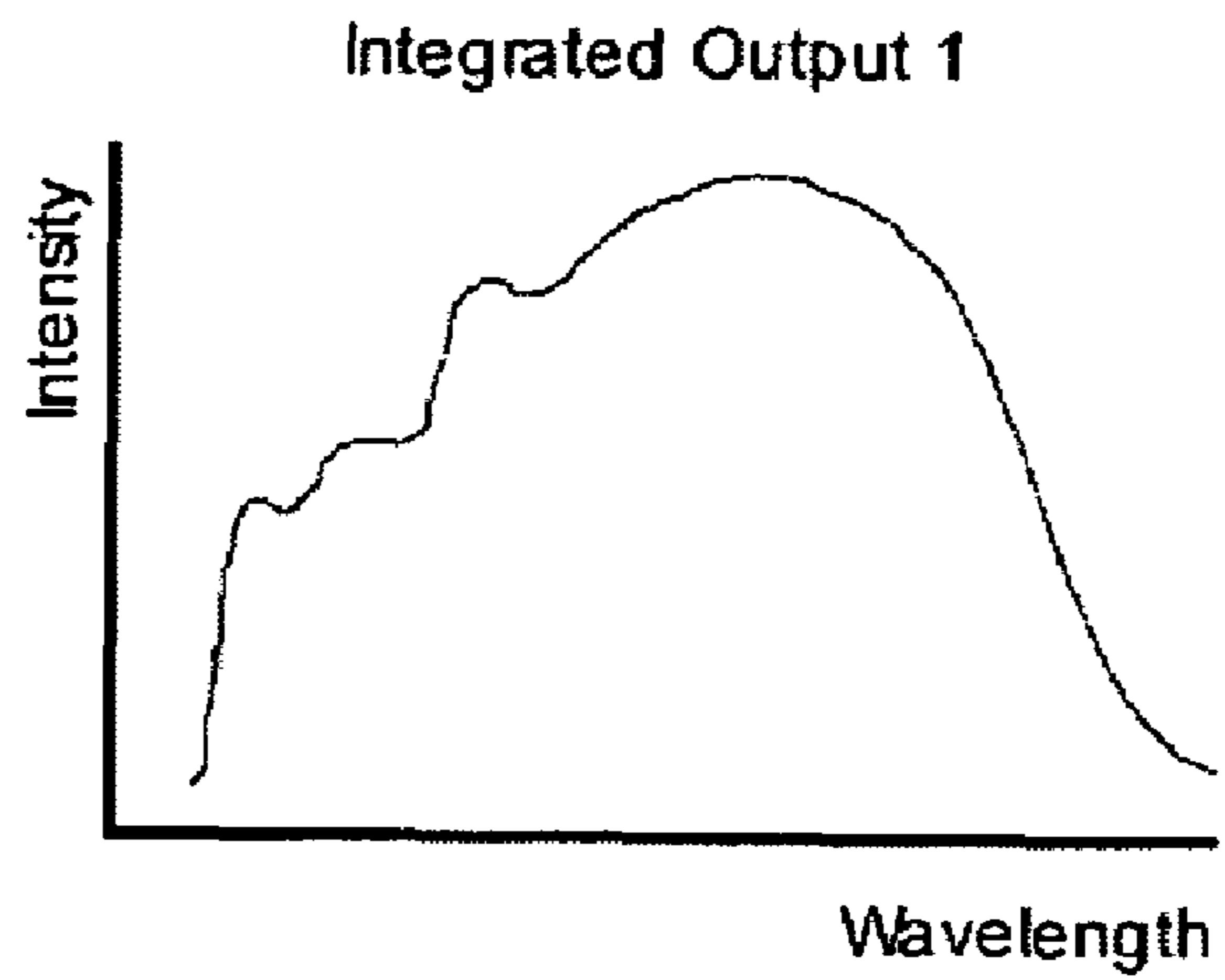


FIG. 3

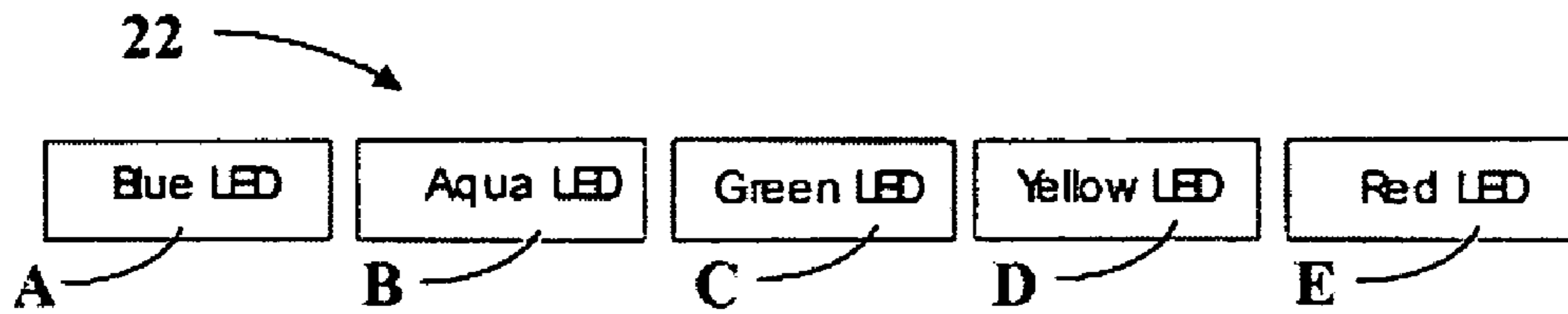


FIG. 4

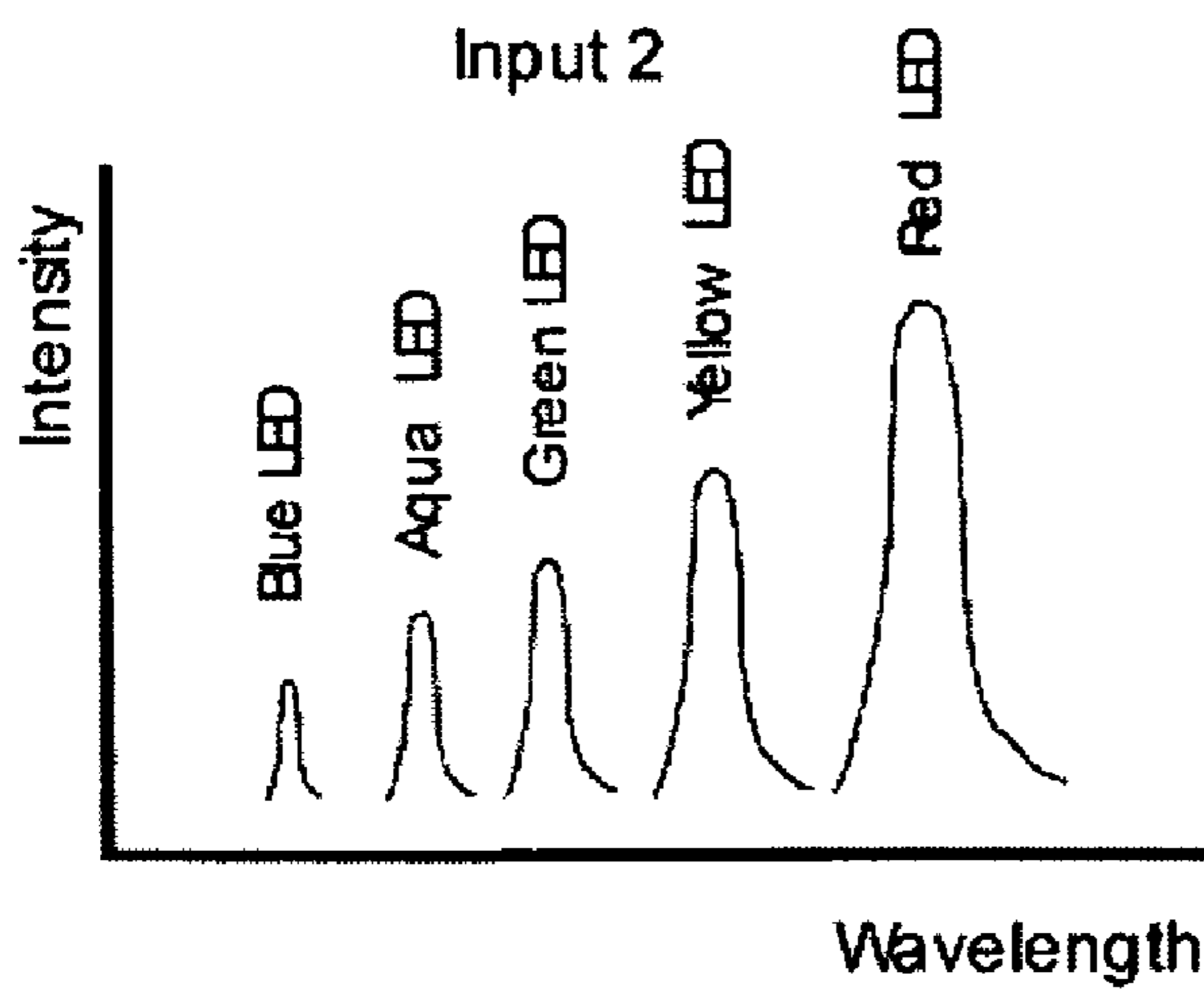


FIG. 5

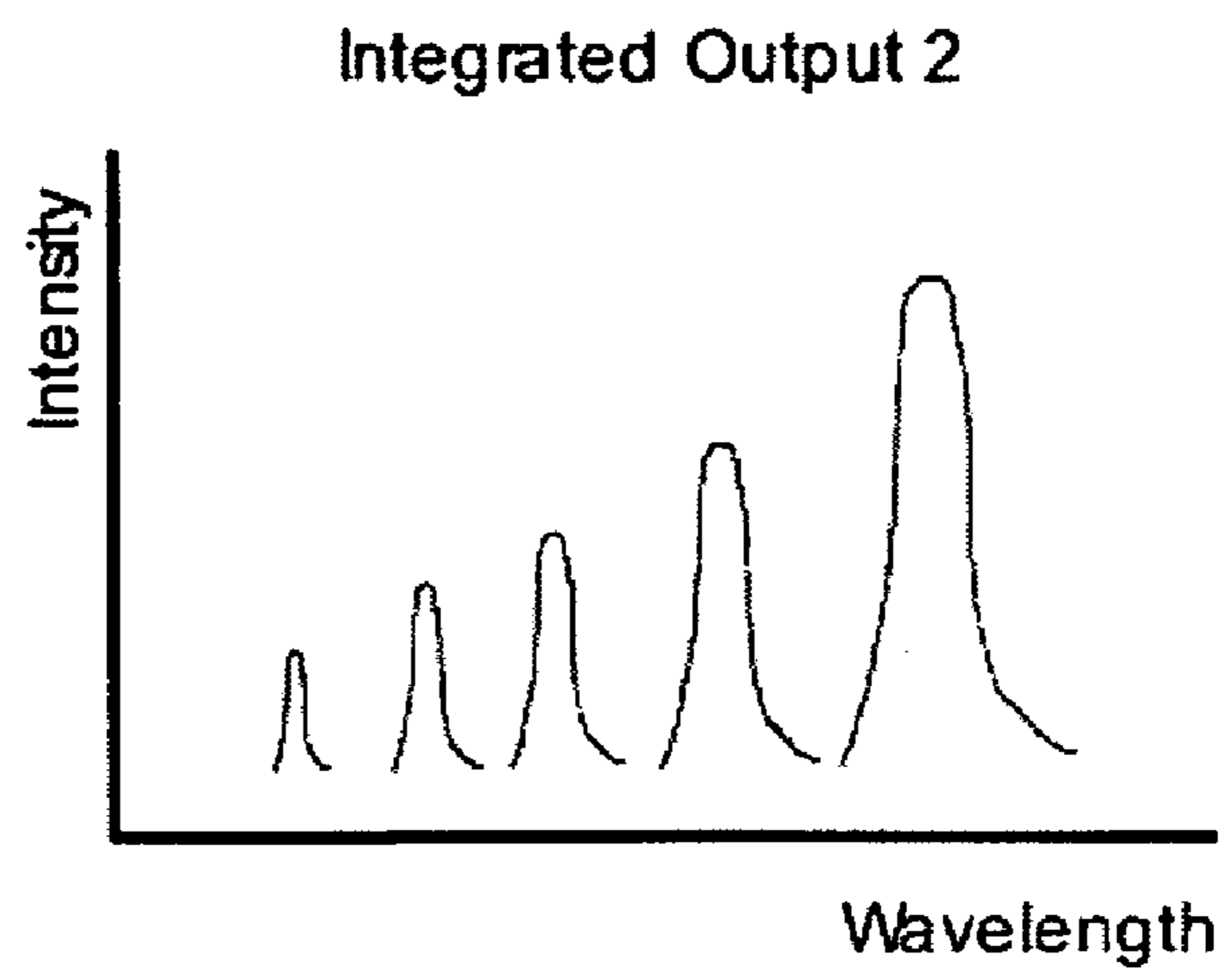


FIG. 6



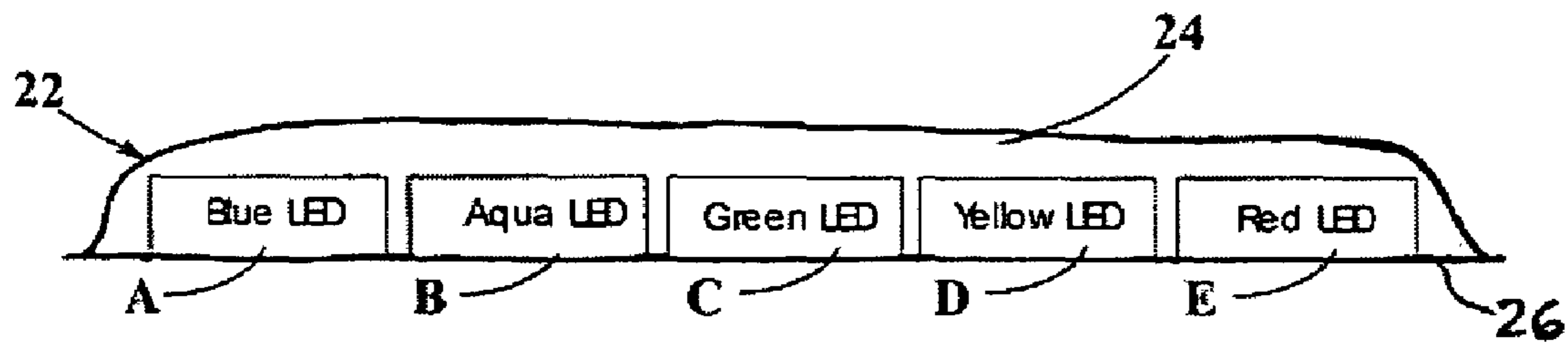


FIG. 7

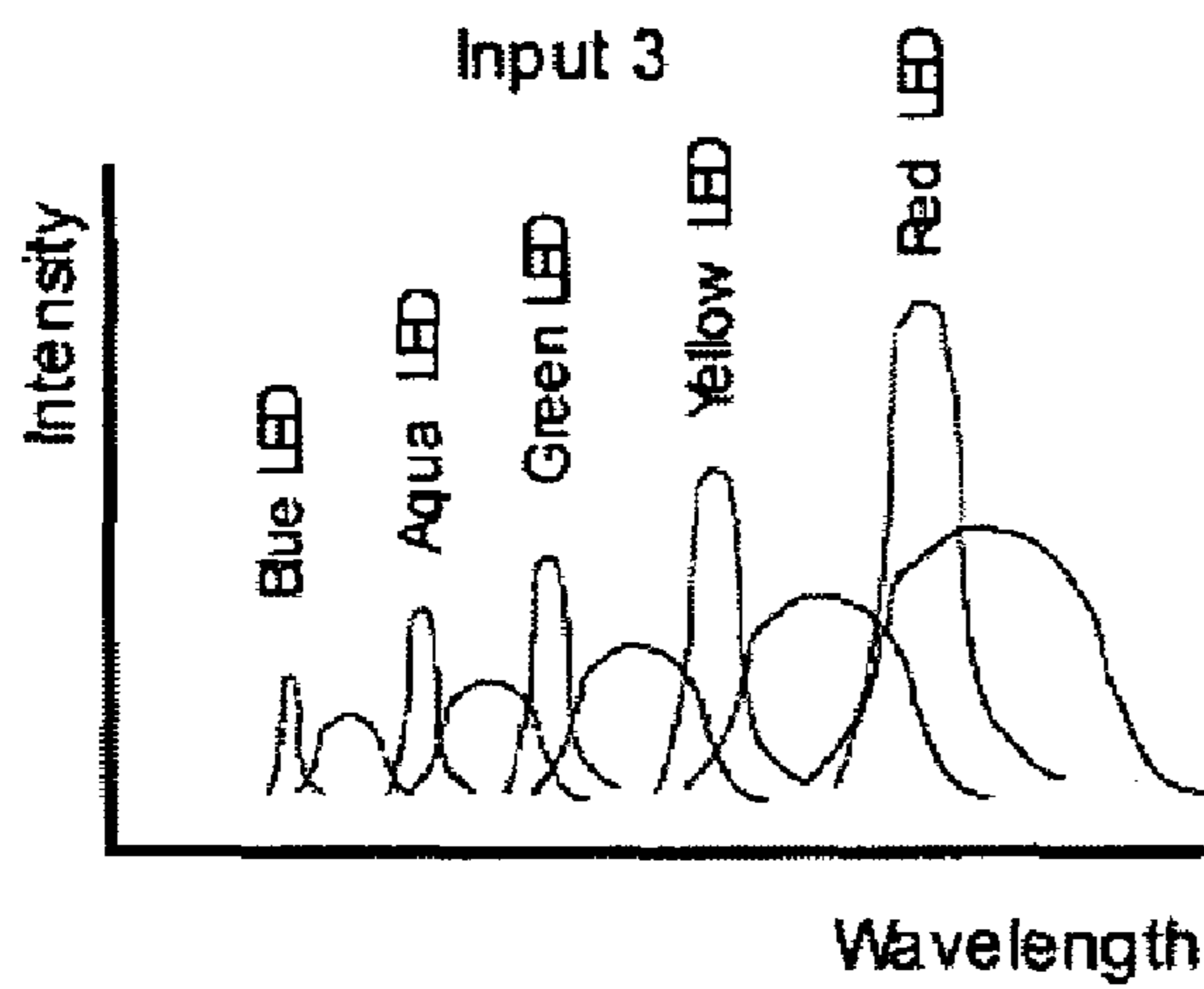


FIG. 8

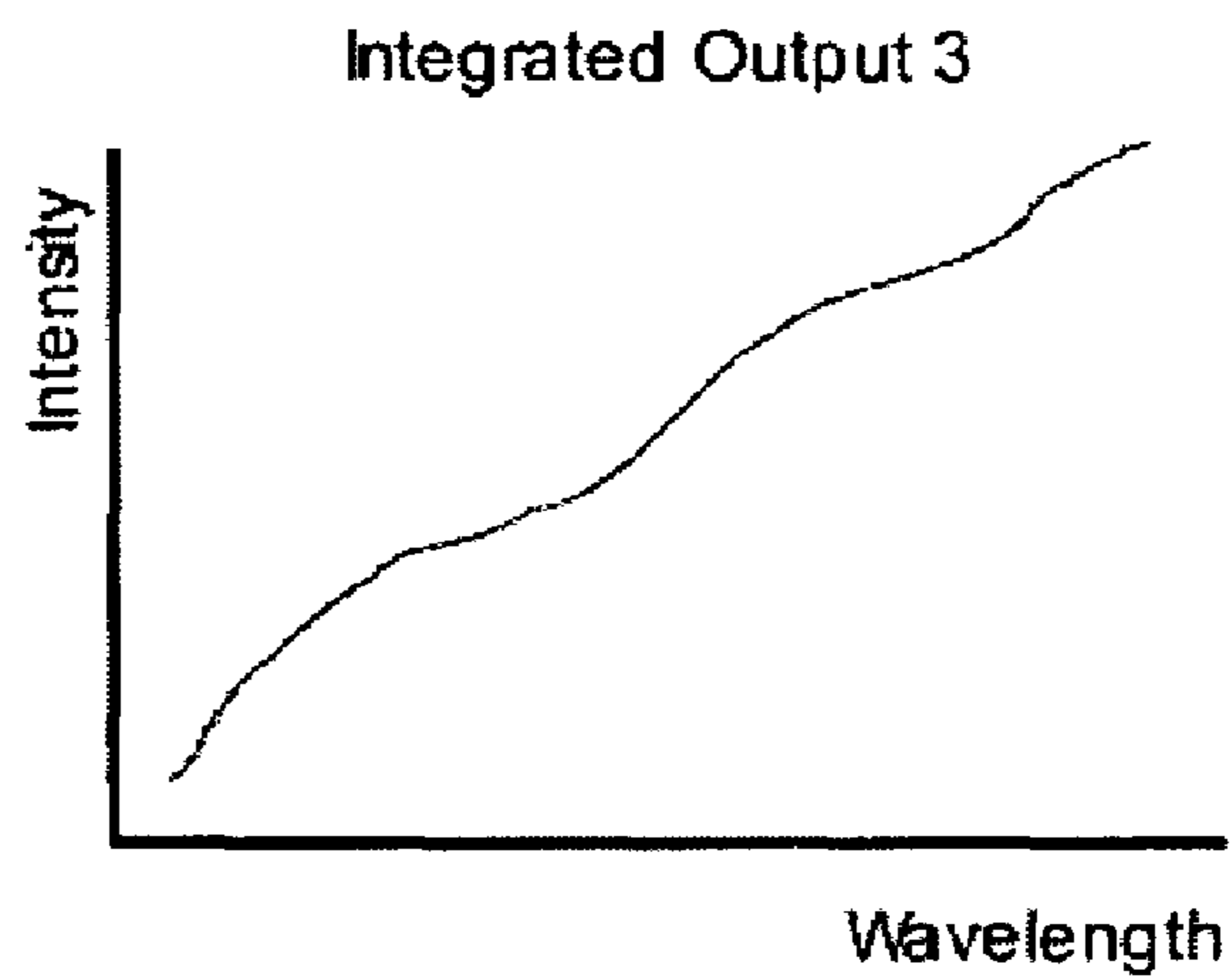


FIG. 9

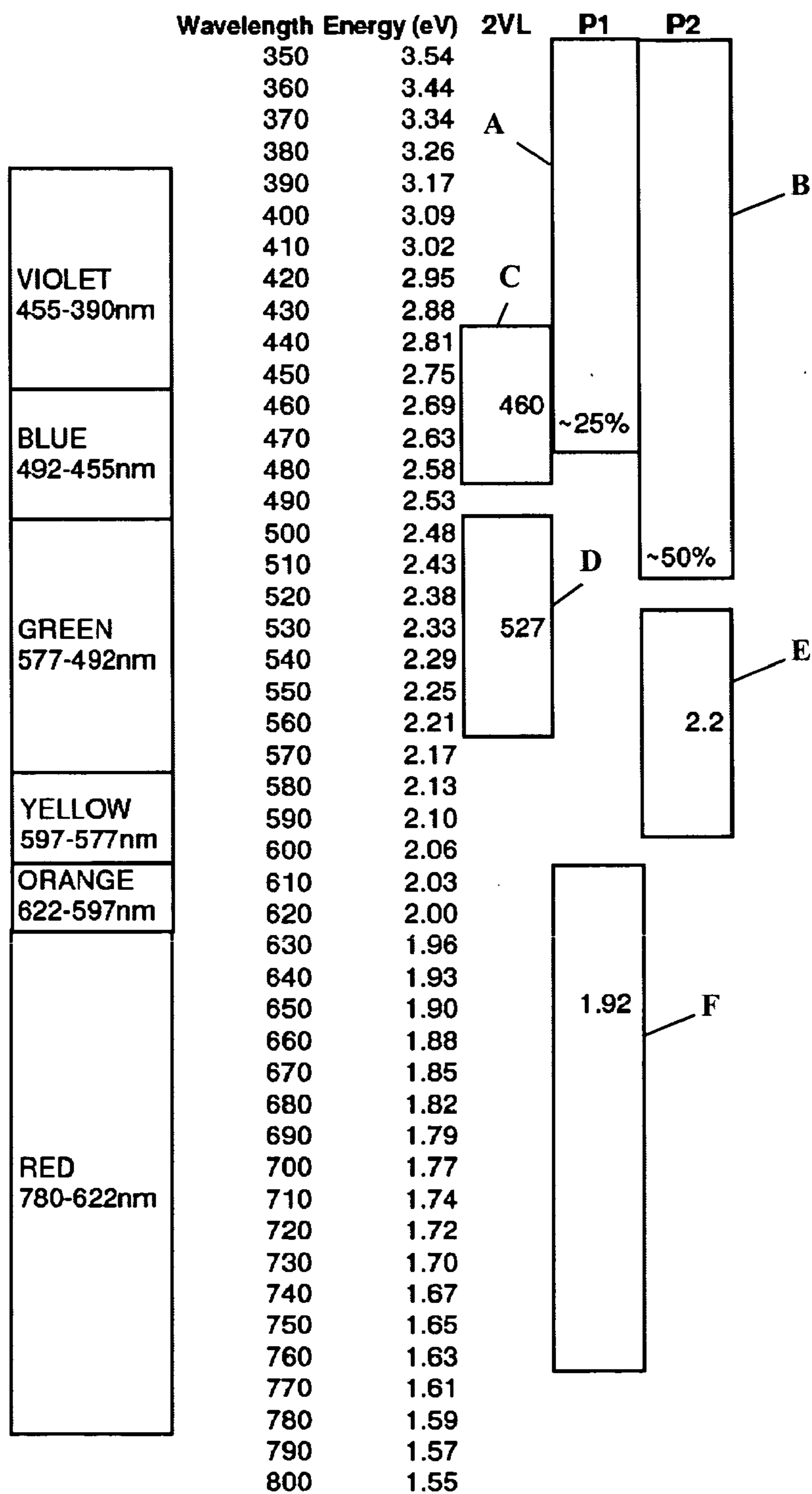


FIG. 10



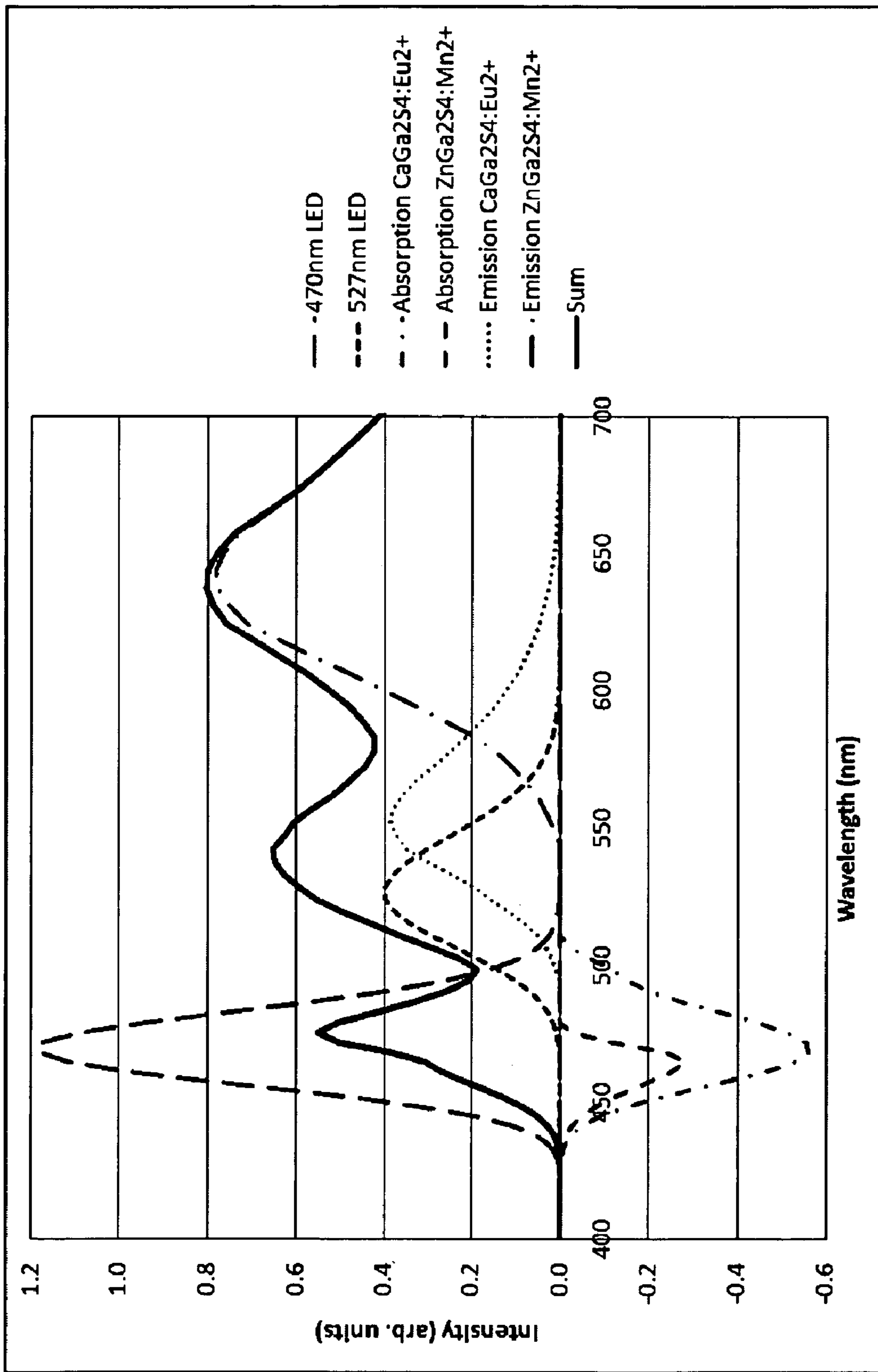


FIG 11

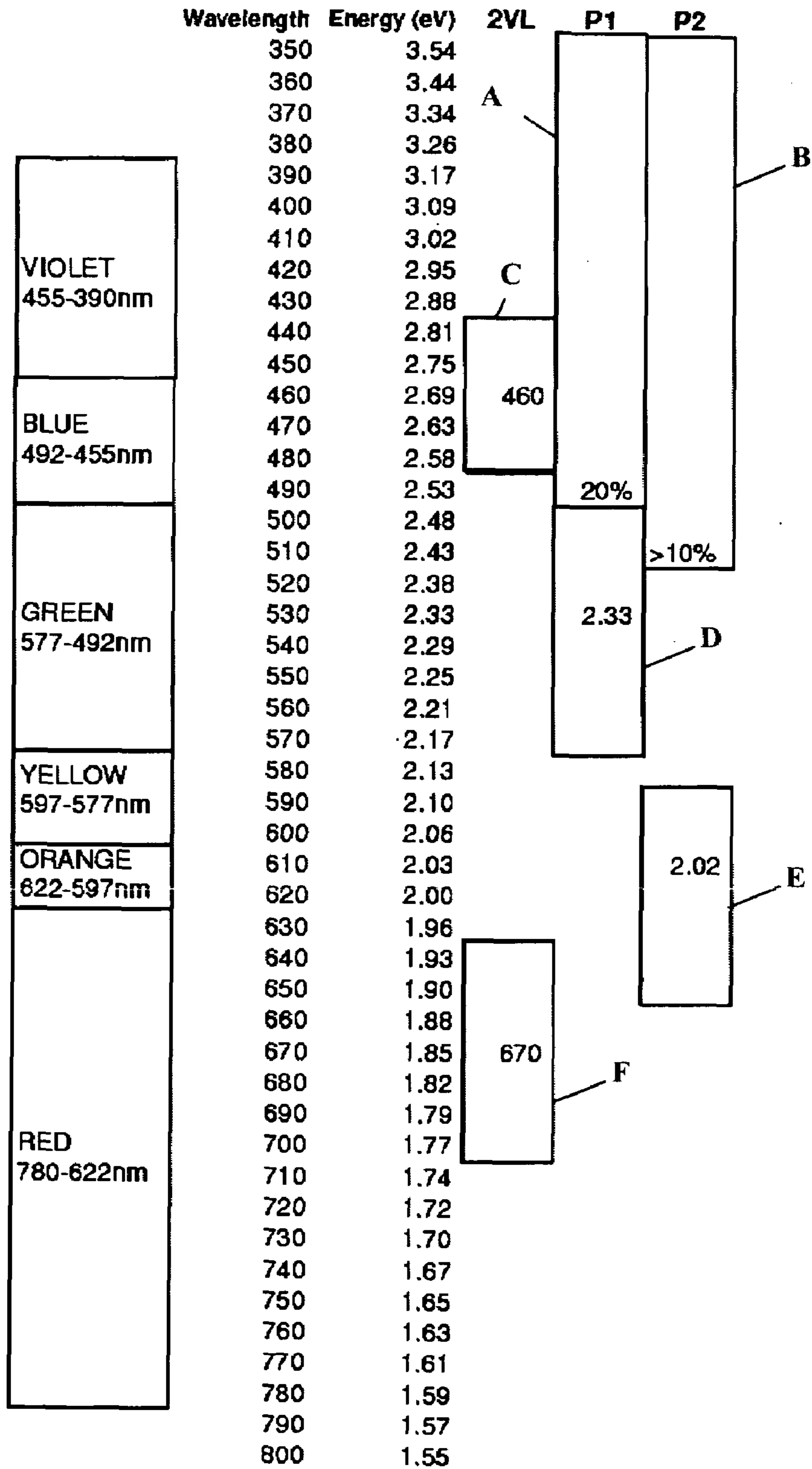


FIG. 12

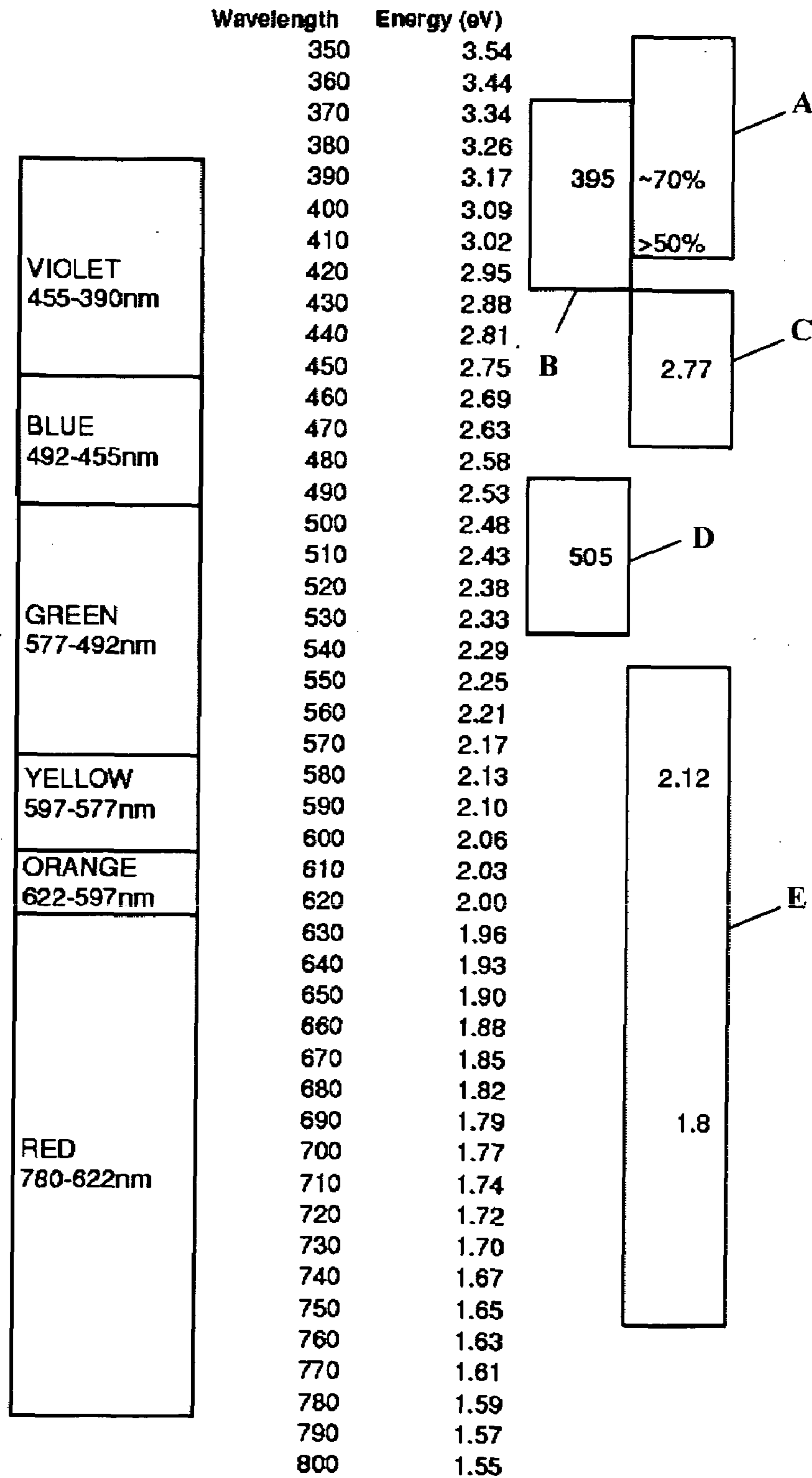


FIG. 13



# LIGHT EMISSION DEVICE AND METHOD UTILIZING MULTIPLE EMITTERS AND MULTIPLE PHOSPHORS

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

This invention relates generally to light emission devices incorporating light emitting diode (LED) and phosphor components.

### 2. Description of the Related Art

In the illumination art, a variety of approaches have been employed to produce light of desired spectral character.

LEDs have come into widespread usage as a result of their advantages, which include small size, long life, low energy consumption, and low heat generation.

U.S. Pat. No. 6,513,949 issued Feb. 4, 2003 describes a hybrid lighting system for producing white light, including at least one LED and a phosphor-LED, in which the color and number of the LEDs and/or the phosphor of the phosphor-LED may be varied.

U.S. Pat. No. 6,600,175 issued Jul. 29, 2004 describes a light emitting assembly including an LED emitting a first, relatively shorter wavelength radiation, and a down-converting luminophoric medium, e.g., phosphoric medium, that in exposure to such first radiation, responsively emits a second, relatively longer wavelength radiation.

White LED devices have been commercialized that utilize a blue LED and a YAG phosphor ( $Y_3Al_5O_{12}$  doped with cerium) that partially absorbs blue radiation (centered on 470-480 nm) from the blue LED and emits light having a broad wavelength range with a dominant yellow characteristic (centered on ~550-600 nm).

The commercially available LED/phosphor devices for production of white light do not provide high conversion efficiency color rendering in various spectral regimes of interest. For example, in many applications, consumers prefer white light having color (as quantifiable by color temperature and color rendering index values) that matches sunlight, conventional incandescent bulb light, or fire light such as candle light.

There is accordingly a continuing need in the art for efficient LED/phosphor illumination systems producing light having a color rendering that closely matches a predetermined spectral distribution.

## SUMMARY OF THE INVENTION

The present invention relates to light emission devices incorporating light emitting diode (LED) and phosphor components.

In one aspect, the invention relates to a light emission device including: at least two LED dies having differing spectral output from one another; and phosphor material including one or more phosphors, arranged to receive spectral output from at least one of the LED dies and to responsively emit a phosphor output as at least part of spectral output of the light emission device.

FIG. 11 shows individual emission spectra for a ~470 nm LED (having a spectral output centered at 470 nm), a ~527 nm LED (having a spectral output centered at 527 nm), a  $CaGa_2S_4:Eu^{2+}$  phosphor, and a  $ZnGa_2S_4:Mn^{2+}$  phosphor; individual absorption spectra for the  $CaGa_2S_4:Eu^{2+}$  phosphor and the  $ZnGa_2S_4:Mn^{2+}$  phosphor; and an aggregated emission spectral distribution (labeled "Sum") for a combination of the foregoing two LEDs and two phosphors.

Other aspects, features and embodiments of the invention will be more fully apparent from the ensuing description and claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional elevation view of a light emission device according to one embodiment of the invention.

FIG. 2 is a graph of intensity as a function of wavelength, for each of the LED die elements and phosphors employed in the light emission device of FIG. 1, as isolated components.

FIG. 3 is a graph of intensity as a function of wavelength, for the integrated output of the light emission device of FIG. 1.

FIG. 4 is an LED multiple die array including five different LED die colors (shown as Blue LED, Aqua LED, Green LED, Yellow LED and Red LED).

FIG. 5 is a graph of intensity as a function of wavelength, for each of the LED die elements employed in the FIG. 5 LED array, as isolated components.

FIG. 6 is a graph of intensity as a function of wavelength, as the integrated output of the LED array of FIG. 4.

FIG. 7 is a simplified schematic depiction of a light emission device according to another embodiment of the invention, incorporating an LED multiple die array including five different LED die colors (shown as Blue LED, Aqua LED, Green LED, Yellow LED and Red LED) and a phosphor mixture overlying the multiple die array.

FIG. 8 is a graph of intensity as a function of wavelength, for each of the LED die elements and phosphor species employed in the FIG. 7 light emission device, as isolated components.

FIG. 9 is a graph of intensity as a function of wavelength, as the integrated output of the light emission device of FIG. 7.

FIG. 10 is a graphical depiction showing wavelength, in nm, and energy, in electron volts, and associated bars showing visible light spectrum, excitation range and spectral region spanned by emission, for a light emission device according to one embodiment of the invention, including two visible light LEDs (green and blue) and two phosphors.

FIG. 11 shows the spectral distribution arising from a combination of a 470 nm LED, a 527 nm LED, a  $CaGa_2S_4:Eu^{2+}$  phosphor and a  $ZnGa_2S_4:Mn^{2+}$  phosphor.

FIG. 12 is a graphical depiction showing wavelength, in nm, and energy, in electron volts, and associated bars showing visible light spectrum, excitation range and spectral region spanned by emission, for a light emission device according to another embodiment of the invention, including two visible light LEDs (blue and red) and two phosphors excited only by the blue LED.

FIG. 13 is a graphical depiction showing wavelength, in nm, and energy, in electron volts, and associated bars showing visible light spectrum, excitation range and spectral region spanned by emission, for a light emission device according to still another embodiment of the invention, including two LEDs (ultraviolet and blue) and one phosphor.

## DETAILED DESCRIPTION AND PREFERRED EMBODIMENTS OF THE INVENTION

The present invention relates to light emission devices incorporating light emitting diode (LED) and phosphor components.

Light emission devices of the invention enable excellent color rendering to be achieved by the provision of at least two LED dies having differing spectral character from one another, and a phosphor material including one or more phos-



phors. The phosphor material is arranged to receive energy from at least one of the multiple LED dies and to responsively emit a phosphor output, as at least part of spectral output of the light emission device. The light emission device has a spectral output that differs from the spectral character of each of the LED dies, and that differs from the phosphor output.

By integrating the emissions of the multiple LED dies and the phosphor material containing at least one phosphor component, the light emission device of the invention may be constituted to achieve a superior color rendering that matches predetermined spectral distributions of light, e.g., sunlight, candle light (or other fire), or light produced by incandescent bulbs.

By way of specific example, the light emission device of the invention may be fabricated to provide a white light output having a color temperature in one of the following white light color temperature regimes (A), (B) and (C):

(A) white light having a color temperature in a range of from 1350° K to 1550° K;

(B) white light having a color temperature in a range of from 2400° K to 3550° K;

(C) white light having a color temperature in a range of from 4950° K to 6050° K.

As further specific examples, the color temperature of candles is ~1500° K, the color temperature of incandescent bulbs is ~2680-3000° K, the color temperature of sunrise and sunset is ~3200° K, and the color temperature of a sunny day at noon is ~5500° K. By appropriate selection of LED die components and phosphor species, a close approach to the color temperature of interest can be achieved in the light output of the light emission device.

In various specific embodiments of the invention, such as those illustratively mentioned above, the spectral output of the light emission device can be white light. In other embodiments, the spectral output of the light emission device can be light having a specific color other than white light. In still further embodiments, the spectral output of the light emission device may include output that is outside the visible light spectrum.

The invention achieves superior color rendering at good conversion efficiency, and provides degrees of freedom in light emission device design that permit optimal spectral outputs to be achieved, e.g., of a specific spectral profile, or of a spectral character that is resistant to color change over the service life of the device. In the latter respect, it is known that phosphors and LEDs tend to age, leading to color changes over time. The light emission device of the invention, by virtue of its multiple LED die components and one or more phosphor components, may be fabricated and arranged to compensate for aging of LEDs and/or phosphors.

It is contemplated by the invention to utilize a predetermined combination of LED(s) and phosphor(s) that are matched to one another in their aging profiles so that there is a consistent aging of the overall device during its service life, so that the color of the output light is maintained over the entire service life, albeit possibly changing in intensity as the device ages. In this respect, it is pointed out that the lifetimes of LEDs are typically measured in the tens of thousands of hours, and that the change in output over such period of time may be relatively small as regards the LEDs of the device.

More generally, the invention contemplates the combination of LEDs and phosphors that are selectively matched in the device including same, to achieve a predetermined character of output emission.

It also is contemplated by the invention, in another embodiment thereof, to use a combination of LEDs and phosphors that are matched in the light emission device, to provide a

change of color at a predetermined point in the service life of the device. For such purpose, the change of color may be relatively rapid in transition, e.g., to prompt an action on the part of a user or a service technician, such as change-out of the illumination device, or change-out of a battery or other power supply means for such device, or other maintenance or service or other action that is desirably carried out after a period of operation and that is indicatable by a prompting color change.

Although the invention is discussed primarily herein in reference to the generation of a visible illumination output, i.e., in a visible illumination spectrum, the invention nonetheless also is broadly applicable to the generation of emission outputs in non-visible spectral regions, e.g., in an IR spectrum, UV spectrum or other non-visible spectrum.

The light emission device of the invention differs from prior LED-phosphor devices, in the provision of multiple differing LED dies, each associated with the phosphor material in the device.

The phosphor material can contain one or more than one phosphor species, as desired in a specific end use application of the invention.

The phosphor material is stimulated by radiation from LED die element(s) of the light emission device, so as to produce a phosphor output of particular spectral character. The spectral output of the overall device therefore will be a composite radiation that will be "smoothed" or otherwise blended, in relation to a corresponding device with only a single LED die. Individual phosphor species can be selected to absorb all or substantially all of the radiation emitted by a given LED die, or alternatively to absorb only a portion of the incident radiation thereon derived from the LED die while allowing the remainder of the emission from the LED die to transmit unabsorbed from the light emission device.

In one embodiment, the light emission device is provided as a unitary article including the multiple LED dies and phosphor(s) in a protective package, in which the multiple dies are arranged in an array overlaid by the phosphor material. The multiple LED dies can for example be positioned on one or more reflector cups or other support structure, with the phosphor material overlying the dies being provided as a layer of the phosphor material. The phosphor material when including multiple phosphor species can be constituted as a uniform, e.g., substantially homogeneous, mixture of the respective phosphors.

It is contemplated by the invention to shape the phosphor(s) in an overlying coating or mass on the LED(s) so as to match the thickness of the phosphor to the primary emission of the LED(s), so that the primary emission radiation traverses a generally same thickness of the phosphor coating or mass, over the entire periphery or output surfaces of the LED(s), to thereby provide better uniformity of spectral output from the illumination device. The invention also contemplates the shaping of the LED die to provide a directionally enhanced emission of primary radiation, or a more uniform emission of primary radiation than is otherwise achievable in the absence of such LED die shaping. In various embodiments of the invention, therefore, it may be desirable to conformally coat phosphor material(s) on the LED die(s) to achieve a predetermined advantageous character of the light emission device.

The phosphor material may be applied over the multiple dies in any suitable manner, e.g., in a curable liquid formulation that is potted, dip-coated, brushed, rolled, sprayed or otherwise applied over the multiple dies, e.g., to form a layer of the phosphor material in which the phosphor component(s) are homogeneously dispersed in the layer.



## 5

It may be desirable in specific applications to place the LED dies in respective individual reflector cups and to mount the cups in a single “bulb” or package. Alternatively, it may be desirable to dispose all LED dies inside a single reflector package. Multiple phosphors may be spread over multiple LED dies or a select phosphor may be spread over a specific LED die. Individual LED die/phosphor packaging may be employed, with each LED die being arranged to impinge emitted energy on a phosphor to produce an integrated output light from the device.

To control the amount of light emitted by the LED dies, current can be sourced individually to each of the dies, if the associated cost and complexity of wiring and power supply arrangements is suitable for the intended end use application. Alternatively, light output of the light emission device can be controlled by variation in die fabrication, die number, die shape, die size (area), contact quality, overall structure resistance, or the like, or other aspects of the LED design.

The phosphor material can be of any suitable type, including for example, YAG (yttrium aluminum garnet) phosphor,  $\text{CaGa}_2\text{S}_4:\text{Eu}^{2+}$  phosphor,  $\text{ZnGa}_2\text{S}_4:\text{Mn}^{2+}$  phosphor, SrSCu+, Na phosphor,  $\text{CaSO}_4:\text{Bi}$  phosphor or any other suitable type of phosphor material.

The phosphor material may include components other than the phosphor(s) per se, such as a carrier medium in which the phosphor(s) are dispersed. In one embodiment, the carrier medium includes a glass or a polymeric composition that is suitably transmissive of emitted energy, e.g., from the LED die and/or phosphor components, to provide the desired character of light output from the light emission device. Polymeric compositions useful for such purpose may be of any appropriate type, including, without limitation, compositions containing polyolefin, polyimide, polysulfone, polyacrylate, polymethacrylate, polycarbonate, or corresponding copolymers.

The phosphor(s) may be dispersed in the carrier medium in a particulate or other discontinuous form, in an amount ensuring a desired character and extent of conversion of LED die-emitted energy to light output from the phosphor(s) in the carrier medium.

The provision of multiple differing LED dies in a unitary packaging with the phosphor material affords a compact and efficient structure capable of producing a high intensity light output of a desired spectral character. By appropriate selection of the different LED dies and phosphor(s) for the light emission device, the radiative emissions of the respective dies and phosphor(s) can be integrated in a manner achieving close matches to predetermined illumination spectra, such as a spectrum of sunlight, candle light or light emitted by a conventional incandescent filament light bulb.

The selection of LED dies and phosphor(s) thus can be made in a manner that results in small energy differences between the LED dies, as illuminating sources, and phosphor(s) emissively responding to impingement of energy from such dies, so that highly efficient light production is achieved.

The invention will now be described in relation to the drawings, in which FIG. 1 is a sectional elevation view of a light emission device 10 according to one embodiment of the invention. The device 10 is shown in a simplified schematic form for clarity of description and illustration, without depiction of additional light extracting optics, e.g., reflecting surfaces, or focusing lens(es), and without depiction of wiring, package leads, bond structures, power supplies or the like.

The light emitting device 10 includes a reflector cup 12 or similar support structure, on which is mounted an LED die 14 of a first color and an LED die 16 of a second color. In a

## 6

specific arrangement of such multi-die array, the first LED die 14 is a blue LED die and the second LED die 16 is a green LED die.

The multi-die array is covered with a phosphor material 18, which in a specific embodiment may include a mixture of two phosphors dispersed in a polymeric matrix such as polycarbonate. The phosphors in the phosphor material 18 are appropriately selected to be excited by radiation emitted from the multi-die array and to responsively emit output radiation, so that the integrated output of the light emission device, deriving from the multi-die array and phosphor material, is of a desired spectral character.

FIG. 2 is a graph of intensity as a function of wavelength, for each of the LED die elements and phosphor species employed in the light emission device of FIG. 1, as isolated components. The graph shows the spectral intensity of emissions of the first LED die (“Blue LED”), second LED die (“Green LED”), first phosphor (“Phosphor 1”) and second phosphor (“Phosphor 2”), when each of such components is considered individually.

FIG. 3 is a graph of intensity as a function of wavelength, for the integrated output (“Integrated Output 1”) of the light emission device of FIG. 1, as including the LED dies and phosphor components whose spectra are shown in FIG. 2. Such integrated output provides a spectral distribution that approximates the spectral distribution of candle light.

FIG. 4 is an LED multiple die array 22 including five different LED die colors. The dies A, B, C, D and E (labeled as “Blue LED,” “Aqua LED,” “Green LED,” “Yellow LED” and “Red LED,” respectively) constitute the multiple die array.

FIG. 5 is a graph of intensity as a function of wavelength, for each of the LED dies employed in the FIG. 5 LED die array, as isolated components. The graph shows the spectral intensity of emissions of the first LED die (“Blue LED”), second LED die, (“Aqua LED”), third LED die (“Green LED”), fourth LED die (“Yellow LED”) and fifth LED die (“Red LED”), when each of such die components is considered individually.

FIG. 6 is a graph of intensity as a function of wavelength, as the white light integrated output (“Integrated Output 2”) of the LED die array of FIG. 4. The integrated light consists of five discrete colors, but there are gaps in the spectral distribution as compared to the spectrum produced by a conventional incandescent filament light bulb.

FIG. 7 is a simplified schematic depiction of a light emission device according to another embodiment of the invention, incorporating an LED multiple die array 22 including five different LED dies A, B, C, D and E (labeled as “Blue LED,” “Aqua LED,” “Green LED,” “Yellow LED” and “Red LED,” respectively), as disposed on a support surface 26 and a phosphor mixture 24 overlying the multiple die array.

FIG. 8 is a graph of intensity as a function of wavelength, for each of the LED die elements and phosphor species employed in the FIG. 7 light emission device, as isolated components. The graph shows the spectral intensity of emissions of the first LED die A (“Blue LED”), the second LED die B (“Aqua LED”), the third LED die C (“Green LED”), the fourth LED die D (“Yellow LED”) and the fifth LED die E (“Red LED”), as well as the distributions associated with the phosphor material in phosphor mixture 24, when each of such LED die and phosphor components is considered individually.

FIG. 9 is a graph of intensity as a function of wavelength, as the integrated output of the light emission device of FIG. 7. By comparison of the spectral distributions of FIG. 6 and FIG. 9, it is seen that the utilization of the phosphor mixture 24 in



the device yields a more smoothly varying spectral distribution that is correspondingly a better spectral match to the desired incandescent bulb spectrum, than the corresponding LED die array lacking the phosphor mixture **24**.

The features and advantages of the invention are more fully shown by the following non-limiting examples, as illustrative of specific aspects, features and embodiments of the invention.

#### EXAMPLE 1

##### Light Emission Device Including Two Visible Light LEDs and Two Phosphors

To encompass the desired spectral range, two LEDs, an X-Brite deep blue (having a spectral output centered at 460 nm and extending between ~440 nm and ~480 nm) LED and an X-Brite green (having a spectral output centered at 527 nm and extending between ~500 nm and ~560 nm) LED, both commercially available from Kingbright Corporation, Taipei, Taiwan, are utilized to fabricate a light emission device of the type shown in FIG. 2. The LEDs function as light sources and excite a phosphor mixture including two phosphors. The first phosphor in the phosphor mixture is a  $\text{CaGa}_2\text{S}_4:\text{Eu}^{2+}$  phosphor, which emits a yellowish-green light and which is excited with light having a wavelength shorter than 510 nm (~50% absorption). The second phosphor in the phosphor mixture is a  $\text{ZnGa}_2\text{S}_4:\text{Mn}^{2+}$  phosphor, which emits an orange-red light and which is excited by light having a wavelength shorter than about ~480 nm (~25% absorption). The die size of each of the two LED dies, and the concentration of each of the two phosphors in the phosphor mixture, are adjusted to achieve a spectral response similar to natural daylight at noon.

FIG. 10 is a graphical depiction showing wavelength, in nm, and energy, in electron volts, and associated bars showing visible light spectrum (at left), excitation spectral ranges (A, B) and emission spectral ranges (C, D, E, F), for a light emission device according to one embodiment of the invention, including two visible light LEDs (green and blue, with emission spectral ranges D and C, respectively) and two phosphors with emission spectral ranges E and F). In FIG. 10, the bars C, D, E and F show the spectral region covered by emissions of the two LEDs and two phosphors of the device, and bars A and B show the excitation ranges of the two phosphors of the device.

FIG. 11 shows individual emission spectra for a very similar device including a ~470 nm LED (i.e., having a spectral output centered at 470 nm), a ~527 nm LED (i.e., having a spectral output centered at 527 nm), a  $\text{CaGa}_2\text{S}_4:\text{Eu}^{2+}$  phosphor, and a  $\text{ZnGa}_2\text{S}_4:\text{Mn}^{2+}$  phosphor; individual absorption spectra (represented as negative absorption units) for the foregoing two phosphors; and an aggregated emission spectral distribution (labeled "Sum") for the combination of the foregoing two LEDs and two phosphors. The LED emission intensity and the phosphor concentrations have been adjusted to yield the spectral distribution shown in the graph.

#### EXAMPLE 2

##### Blue and Red LEDs with Two Phosphors Excited Only by the Blue

To encompass the desired spectral range, two LEDs, an X-Brite deep blue (460 nm) LED and an X-Brite red (670 nm) LED, both commercially available from Kingbright Corporation, Taipei, Taiwan, are utilized to fabricate a light emission

device of the type shown in FIG. 2. The LEDs function as light sources and the blue is used to excite a phosphor mixture including two phosphors. The first phosphor in the phosphor mixture is a  $\text{SrSCu},\text{Na}$  phosphor, which emits a green light centered on 530 nm and which is excited with light shorter than ~490 nm (~20% absorption). The second phosphor in the phosphor mixture is a  $\text{CaSO}_4:\text{Bi}$  phosphor, which emits a yellow orange light and which is excited by light shorter than about 510 nm (~10% absorption). The LED dies are coated by the phosphors during manufacture, with all dies being mounted in a single package to facilitate fabrication and assembly. The phosphors are excited by the blue light emitted from the blue LED die, but simply transmit the red light emitted by the red LED die. The die size of each of the two LED dies, and the concentration of each of the two phosphors in the phosphor mixture, are adjusted to achieve a spectral response similar to natural daylight at noon.

FIG. 12 is a graphical depiction showing wavelength, in nm, and energy, in electron volts, and associated bars showing visible light spectrum, excitation range and spectral region spanned by emission, for the light emission device including the two visible light LEDs (blue and red) and the mixture of two phosphors excited only by the blue LED die emission. In FIG. 11, the bars C, D, E and F show the spectral region covered by the emission from the device, and bars A and B show the excitation range for the device.

#### EXAMPLE 3

##### Ultraviolet and Blue LEDs and One Phosphor

To encompass the desired spectral range approaching a solar spectrum, two LEDs, a MegaBrite ultraviolet (having output centered at 395 nm) LED, commercially available from Cree, Inc., Durham, N.C., USA, and an X-Brite signal green (having output centered at 505 nm) LED, commercially available from Kingbright Corporation, Taipei, Taiwan, are employed to fabricate a light emission device of the general type shown in FIG. 2, in which the phosphor material contains only one phosphor. The ultraviolet LED acts to excite the phosphor while the green LED contributes to the emission to ensure that the spectral distribution produced by the light emission device closely matches the desired solar spectrum. The phosphor employed in the device is a  $\text{CaMgSi}_2\text{O}_6:\text{Eu}^{2+},\text{Mn}^{2+}$  phosphor, which emits in the blue, yellow-green, orange and red. This phosphor is transmissive to green and the X-Brite signal green LED produces light in this spectral region. The phosphor is excited by light shorter than 410 nm (~50% absorption). The die size of each of the two LED dies, and the concentration of the phosphor, are adjusted to achieve a spectral response similar to natural daylight at noon.

FIG. 13 is a graphical depiction showing wavelength, in nm, and energy, in electron volts, and associated bars showing visible light spectrum, excitation range and spectral region spanned by emission, for such light emission device incorporating two LEDs (ultraviolet and blue) and one  $\text{CaMgSi}_2\text{O}_6:\text{Eu}^{2+},\text{Mn}^{2+}$  phosphor. In FIG. 12, the bars B, C, D and E show the spectral region covered by the emission from the device, and bar A shows the excitation range for the device.

While the invention has been described herein with reference to specific aspects, features and embodiments, it will be recognized that the invention is not thus limited, but rather extends to and encompasses other variations, modifications and alternative embodiments. Accordingly, the invention is intended to be broadly interpreted and construed to encompass all such other variations, modifications, and alternative



9

embodiments, as being within the scope and spirit of the invention as hereinafter claimed.

What is claimed is:

1. A light emission device, comprising:
  - a first electrically activated solid state emitter having a first spectral output;
  - a second electrically activated solid state emitter having a second spectral output that differs from the first spectral output;
  - a first phosphor material arranged to interact with at least the first emitter and responsively emit a third spectral output; and
  - a second phosphor material arranged to interact with at least the second emitter, and responsively emit a fourth spectral output that differs from the third spectral output;
 wherein at least one of the first phosphor material and the second phosphor material is disposed relative to the emitters in an amount that differs among the first emitter and the second emitter, and wherein each of the first, second, third, and fourth spectral output comprises output in the visible range.
2. The light emission device of claim 1, wherein at least one of the first phosphor material and the second phosphor material is arranged to interact with both the first emitter and the second emitter.
3. The light emission device of claim 1, wherein the first phosphor material is arranged to receive significant spectral output from only the first emitter, and the second phosphor material is arranged to receive significant spectral output from only the second emitter.
4. The light emission device of claim 1, wherein each of the first spectral output, the second spectral output, the third spectral output, and the fourth spectral output differs from the other.
5. The light emission device of claim 1, wherein any of the first phosphor material and the second phosphor material is conformally coated on at least one of the first emitter and the second emitter.
6. The light emission device of claim 1, wherein the first emitter differs substantially in size from the second emitter.
7. The light emission device of claim 1, further comprising a common covering material comprising any of a glass composition and a polymeric composition, wherein said covering material is arranged to transmit each of the first spectral output, second spectral output, third spectral output, and fourth spectral output therethrough.
8. A method of generating light, comprising:
  - exciting a first electrically activated solid state emitter having a first spectral output; and
  - exciting a second electrically activated solid state emitter having a second spectral output, said second spectral output differing from said first spectral output;
 wherein a first phosphor material is arranged to interact with at least the first emitter to responsively emit a third spectral output from said first phosphor material;
 wherein a second phosphor material is arranged to interact with at least the second emitter to responsively emit a fourth spectral output from said second phosphor material, said fourth spectral output differing from said third spectral output; and
 wherein at least one of the first phosphor material and the second phosphor material is disposed relative to the emitters in an amount that differs among the first emitter and the second emitter, and wherein each of the first, second, third, and fourth spectral output comprises output in the visible range.

10

9. A light emission device comprising:
  - a first electrically activated solid state emitter having a first spectral output including a first color peak in the visible range;
  - a second electrically activated solid state emitter having a second spectral output including a second color peak in the visible range;
  - a first phosphor material arranged to interact with at least the first emitter and responsively emit a third spectral output including a third color peak in the visible range; and
  - a second phosphor material arranged to interact with at least the second emitter and responsively emit a fourth spectral output including a fourth color peak in the visible range;
 wherein each of the first color peak, second color peak, third color peak, and fourth color peak differs from the other, and an aggregated spectral output of the device includes the first color peak, second color peak, third color peak, and fourth color peak.
10. The light emission device of claim 9, wherein at least one of the first phosphor material and the second phosphor material is disposed relative to the emitters in an amount that differs among the first emitter and the second emitter.
11. The light emission device of claim 9, wherein at least one of the first phosphor material and the second phosphor material is arranged to interact with both the first emitter and the second emitter.
12. The light emission device of claim 9, wherein the first phosphor material is arranged to receive significant spectral output from only the first emitter, and the second phosphor material is arranged to receive significant spectral output from only the second emitter.
13. The light emission device of claim 9, wherein any of the first phosphor material and the second phosphor material is conformally coated on at least one of the first emitter and the second emitter.
14. The light emission device of claim 9, adapted to provide an aggregated spectral output of white light.
15. The light emission device of claim 9, adapted to provide an aggregated spectral output that substantially matches an illumination spectrum of sunlight, candle light, or incandescent filament light.
16. The light emission device of claim 9, adapted to provide an aggregated spectral output of white light having a color temperature in a range of from 1350° K to 1550° K.
17. The light emission device of claim 9, adapted to provide an aggregated spectral output of white light having a color temperature in a range of from 2400° K to 3550° K.
18. The light emission device of claim 9, adapted to provide an aggregated spectral output of white light having a color temperature in a range of from 4950° K to 6050° K.
19. The light emission device of claim 9, wherein spectral output of each of the first emitter and the second emitter traverses a different thickness of phosphor material.
20. The light emission device of claim 9, further comprising a common covering material comprising any of a glass composition and a polymeric composition, wherein said covering material is arranged to transmit each of the first spectral output, second spectral output, third spectral output, and fourth spectral output therethrough.
21. The light emission device of claim 20, wherein any of the first phosphor material and the second phosphor material is dispersed in the common covering material.
22. The light emission device of claim 9, wherein the first emitter and the second emitter differ substantially in size.



## 11

23. The light emission device of claim 9, wherein the first emitter, the second emitter, the first phosphor material, and the second phosphor material are disposed in a unitary package

24. The light emission device of claim 9, wherein the first emitter comprises a first LED die and the second emitter comprises a second LED die.

25. The light emission device of claim 9, wherein at least one of the first emitter, the second emitter, the first phosphor material, and the second phosphor material has a first aging profile including a degradation of light emission over its service life, and at least one other of the first emitter, the second emitter, the first phosphor material, and the second phosphor material has a second aging profile at least partially compensating said degradation of light emission inherent to said first aging profile.

26. The light emission device of claim 9, wherein at least two of said first emitter, second emitter, first phosphor material, and second phosphor material are matched in aging character thereof to provide a predetermined character of spectral output of the light emission device over the operating life of the light emission device.

27. The light emission device of claim 26, wherein said predetermined character of spectral output of the light emission device includes a transition in color of spectral output of the light emission device at a predetermined time during said life of the device.

28. The light emission device of claim 9, further comprising a third electrically activated solid state emitter having a fifth spectral output that differs from each of the first and second spectral output.

## 12

29. The light emission device of claim 28, further comprising a third phosphor material having a sixth spectral output that differs from each of the third and fourth spectral output.

30. The light emission device of claim 9, wherein current to each emitter is individually controlled.

31. The light emission device of claim 9, wherein the first emitter and the second emitter are disposed in or on a common reflector.

32. A method of generating light, comprising:

exciting a first electrically activated solid state emitter having a first spectral output including a first color peak in the visible range; and

exciting a second electrically activated solid state emitter having a second spectral output including a second color peak in the visible range;

wherein the first spectral output interacts with a first phosphor material and responsively emits a third spectral output including a third color peak in the visible range;

wherein the second spectral output interacts with a second phosphor material and responsively emits a fourth spectral output including a fourth color peak in the visible range; and

wherein each of the first color peak, second color peak, third color peak, and fourth color peak differs from the other, and an aggregated spectral output of the device includes the first color peak, second color peak, third color peak, and fourth color peak.

\* \* \* \* \*



UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 7,564,180 B2  
APPLICATION NO. : 11/032363  
DATED : July 21, 2009  
INVENTOR(S) : George R. Brandes

Page 1 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Pg, Item (56) page 3, References Cited, FOREIGN PATENT DOCUMENTS, twenty-ninth entry: "JP 2005-124311 A" should be -- JP 2005-142311 A --.

On the Title Pg, Item (56) page 3, References Cited, OTHER PUBLICATIONS, first entry: "Semiconduters" should be -- Semiconductors --.

On the Title Pg, Item (56) page 4, References Cited, OTHER PUBLICATIONS, add: -- "White Light LED, Part Nos. NSPW300BS and NSPW312BS, High Brightness LEDs," Nov. 12, 1999. Publisher: Nichia Corporation. --.

Column 1, lines 60-67: "FIG. 11 shows individual emission spectra for a ~470 nm LED (having a spectral output centered at 470 nm), a ~527 nm LED (having a spectral output centered at 527 nm), a  $\text{CaGa}_2\text{S}_4:\text{Eu}^{2+}$  phosphor, and a  $\text{ZnGa}_2\text{S}_4:\text{Mn}^{2+}$  phosphor; individual absorption spectra for the  $\text{CaGa}_2\text{S}_4:\text{Eu}^{2+}$  phosphor and the  $\text{ZnGa}_2\text{S}_4:\text{Mn}^{2+}$  phosphor; and an aggregated emission spectral distribution (labeled "Sum") for a combination of the foregoing two LEDs and two phosphors" should be -- In another aspect, the invention relates to a method of generating light, including exciting at least two LED dies having differing spectral output from one another, to emit spectral outputs from each of such dies, and impinging the spectral output from at least one of such dies on phosphor material including one or more phosphors, to responsively emit a phosphor output, as a component of spectral output constituting such light --.

Column 2, lines 41-43: "FIG. 11 shows the spectral distribution arising from a combination of a 470 nm LED, a 527 nm LED, a  $\text{CaGa}_2\text{S}_4:\text{Eu}^{2+}$  phosphor and a  $\text{ZnGa}_2\text{S}_4:\text{Mn}^{2+}$  phosphor" should be -- FIG. 11 shows individual emission spectra for a ~470 nm LED (having a spectral output centered at 470 nm), a ~527 nm LED (having a spectral output centered at 527 nm), a  $\text{CaGa}_2\text{S}_4:\text{Eu}^{2+}$  phosphor and a

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 7,564,180 B2  
APPLICATION NO. : 11/032363  
DATED : July 21, 2009  
INVENTOR(S) : George R. Brandes

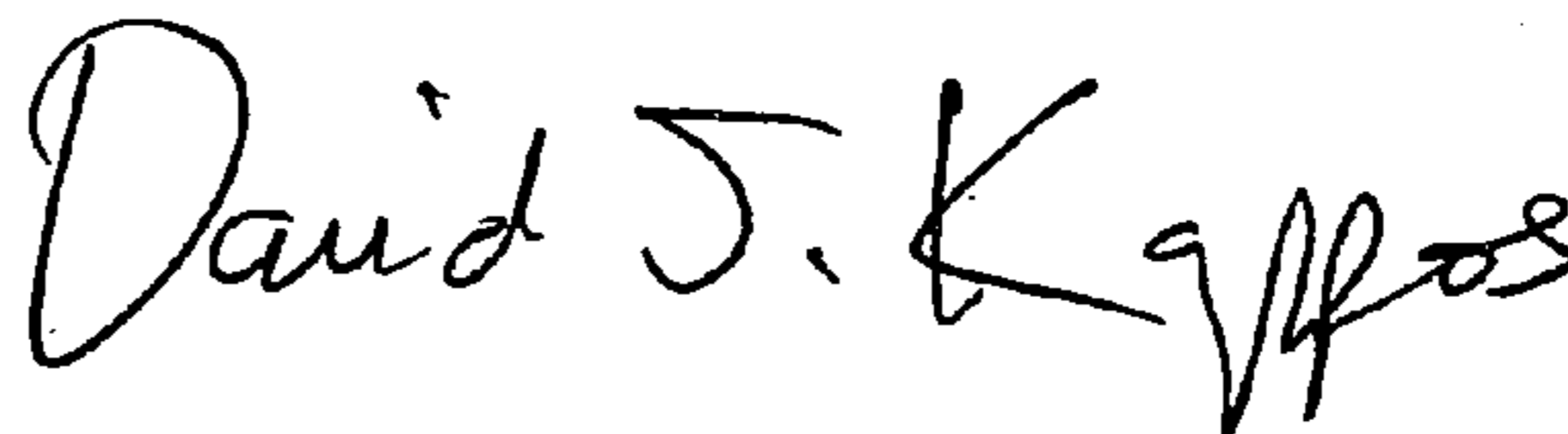
Page 2 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

ZnGa<sub>2</sub>S<sub>4</sub>:Mn<sup>2+</sup> phosphor; individual absorption spectra for the CaGa<sub>2</sub>S<sub>4</sub>:Eu<sup>2+</sup> phosphor and the ZnGa<sub>2</sub>S<sub>4</sub>:Mn<sup>2+</sup> phosphor; and an aggregated emission spectral distribution (labeled "Sum") for a combination of the foregoing two LEDs and two phosphors --.

Signed and Sealed this

Twenty-second Day of December, 2009



David J. Kappos  
*Director of the United States Patent and Trademark Office*